

Performance Evaluation of Retrofitted Solid Masonry Exterior Walls

INTRODUCTION

Many existing buildings in Canada constructed with solid masonry exterior walls are being renovated and converted from their original commercial or industrial use into residential use. In order to increase energy efficiency and occupant comfort, the addition of thermal insulation is desirable. Historically, there has been a concern that adding thermal insulation along the inside face of the wall could increase the risk of condensation and frost formation within the wall system during the heating season, as well as prolong the drying time of the wall. As this combination, under certain conditions, could adversely affect the integrity and durability of the building envelope, unresolved questions remain regarding how to best improve the insulative properties of existing solid masonry walls without compromising their durability.

Conducted in 2003, this research project includes the testing and assessment of the results of a preliminary performance evaluation of nine existing buildings which had recently undergone an insulation retrofit of their solid masonry walls. In addition, a tenth building, which did not undergo any insulation retrofit change despite a change from industrial/commercial usage to residential usage, was included in the study. The study is expected to be the first in a series of evaluations to take place on these same buildings over an interval of every three or four years. The results of the present study are intended as an initial step towards aiding practitioners to elaborate on different retrofit strategies by providing shared knowledge on the historical performance of previously retrofitted solid masonry walls.

CONCERNS RELATED TO INCREASING THERMAL RESISTANCE OF WALLS

The report demonstrates through simple 1 dimensional hygrothermal computer modeling, the theoretical concerns relating to increasing the thermal resistance of existing exterior solid masonry walls by analyzing and comparing the differences in the hygrothermal conditions of an uninsulated masonry wall, an interior insulated masonry wall, and an exterior insulated masonry wall under a steady-state winter design conditions for Montréal. The computer modeling demonstrates that an existing uninsulated solid masonry wall or an exterior insulated masonry wall promotes heat transfer from within the building to aid in warming and drying of the masonry wall.

In contrast, the modeling revealed that an interior insulated masonry wall reduces heat transfer from within the building to the exterior masonry and consequently, reduces the average temperature within the masonry wall and reduces the drying rate of any entrapped moisture within the wall during winter. The report demonstrates that the decrease in the average temperature of the masonry wall caused by adding insulation to the inside face of a solid masonry wall, in combination with any entrapped moisture within the wall (caused by precipitation or condensation), could promote an increased risk of freeze-thaw damage and masonry wall deterioration.

It should be noted that the aforementioned analysis overly simplifies circumstances in both the uninsulated and insulated wall conditions. In the case of the uninsulated wall, heat does not likely flow uniformly out through the wall keeping it warm under all outdoor conditions. Freeze-thaw action will occur within the wall section but closer to the exterior surface. In the case of insulated walls, freeze-thaw action may arise closer to the interior surfaces. Whether or not freeze-thaw action will necessarily cause damage is beyond the scope of this study.

GENERAL GUIDELINES FOR INSULATING SOLID MASONRY WALLS

The report provides general design guidelines to consider when insulating the inside face of a solid masonry as a means of reducing the risks of freeze-thaw damage and masonry deterioration. The guidelines include minimizing rain penetration, controlling indoor humidity preventing water vapour diffusion and air leakage, and minimizing the air pressure differential across the exterior wall.

CASE STUDIES

Nine of the ten buildings reviewed in the report were located in the Montréal area, while the tenth was located in Léry, Québec (Building no.10 on Table 2). Each of the buildings was subjected to a preliminary performance evaluation which included

- interviews with the building manager, owner, or design professional in order to obtain historical data on the retrofit approach
- review of all available construction plans and drawings for the retrofit work
- a non-destructive visual review of the exterior masonry walls of each of the buildings
- computer modeling and comparative review of the results of the hygrothermal conditions within each of the wall systems based upon the composition of the wall system before and after the retrofit

COMPUTER MODELING PARAMETERS

Initial modeling for each of the 10 case studies included in the report was conducted using design parameters for Montréal/Léry winter climate (January, 2.5%) with an exterior ambient temperature of -23 °C, an exterior ambient humidity of 90 per cent RH, interior temperature of 21 °C, and interior humidity of 35 per cent RH. Supplementary modeling was also conducted in several cases in order to determine the threshold of interior relative humidity expected to either produce or eliminate condensation within a given wall assembly.

Due to limitations in the simulation software, the effect of thermal mass, solar heating, and the significant effect of air leakage were not considered in the results generated by the computer simulation. Consequently, the modeling includes the comparative results of the expected rate of condensation under a steady-state condition for each of the wall systems via diffusion only.

Figure 1 of the report presents an example of how the computer modeling was conducted and the typical input of parameters and output of hygrothermal conditions obtained for each case study reviewed and compared. Using the modeling software, the report

describes that the wall construction for each of the case studies were simulated by selecting and entering the appropriate building materials provided for in the software. Once the wall is "assembled" in 2-D within the software, the parameters for winter design conditions were input including the exterior temperature (-23 °C), interior temperature (21 °C), exterior relative humidity (90%), and interior relative humidity (35%).

The typical input results in a 2-D profile view of the wall assembly and depicts the temperature and humidity parameters on the interior and exterior sides of the drawing as shown in the upper left cell of Figure 1 of the report. As shown in the second row of Figure 1, the output provided by the modeling includes a tabulated description of each element of the wall, its individual thermal resistance, and total thermal resistance of the wall assembly in RSI and R-Value units. In addition, the third row of Figure 1, the output of the modeling also includes a chart which displays the change in temperature (red line), vapour pressure (green line), and the saturated vapour pressure (blue line) throughout the wall assembly based upon the input wall construction and the parameters provided. Using this chart, condensation in the wall assembly is said to occur at the point where the vapour pressure line intersects with the saturated vapour pressure line.

Finally, as shown in the fourth row of Figure 1, the output for the modeling also provides textual confirmation that either condensation does occur (Case No. 1) or no condensation occurs (Case No. 2). Where condensation is confirmed to occur, the output also includes a condensation rate (in both g/sq-m/sec and l/sq-m/day) and the dewpoint temperature (°C). The output in either case also provides the heat loss rate of the wall assembly and the approximate cost of materials for the wall assembly.

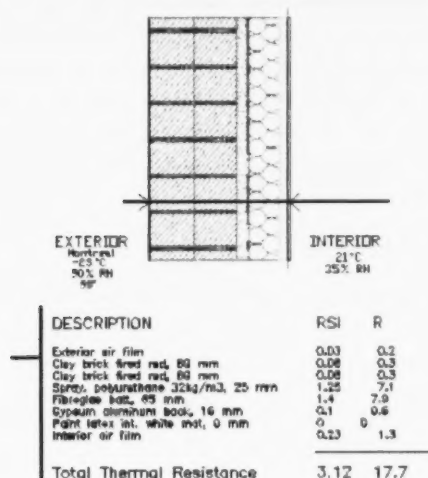
The comparative results of the computer modeling of both the original and the retrofit wall assemblies as presented in the report are shown in Table 1. The analysis of the modeling results conducted in the report was carried out by comparing the results of the rate of condensation obtained by the computer modeling of the original wall assembly (see column 4 of Table 1), versus the results of the rate of condensation obtained by the computer modeling of the retrofit (added interior insulation) wall assembly (see column 9 of Table 1) for each of the nine relevant cases. Wherever the rate of condensation for the retrofit wall assembly is greater than the rate of condensation of the original wall construction, the report concludes that the retrofit action of adding interior insulation to the existing wall assembly in that particular case favours an increase in the rate of condensation via diffusion. In contrast, wherever the rate of condensation for the retrofit wall assembly is less than the rate of condensation of the original wall construction, the report concludes that the retrofit action of adding

interior insulation to the existing wall assembly in that particular case favours a decrease in the rate of condensation via diffusion.

Through the process of the analysis described above, the report indicates that increasing the thermal resistance along the inside face of the existing masonry wall could provoke conditions favorable to increasing the rate of condensation due to diffusion in the wall assembly under identical ambient conditions (temperature and relative humidity) in six of the nine retrofit cases reviewed. Two of the cases

modeled (Case Study Nos. 2 and 8) revealed that the insulation retrofit reduced the rate of condensation for these particular buildings:

In both these cases, the wall assemblies included an air space behind the masonry on the cold side of the air barrier (spray-applied polyurethane) as opposed to the six other cases modeled which either had no air space integrated in their assembly or had an air space located on the warm side of the air barrier. One of the cases (Case Study No. 4) which included a retrofit strategy equipped with a



The materials found in the wall assembly are entered. The resulting envelope detail will be shown in the upper left corner of the output drawing. The conditions for the exterior and interior environments are shown on the respective sides of the assembly.

The thermal resistance values are shown for each element in the wall assembly. The amounts are listed in RSI and R-value units.

The chart on the left displays the temperature curve as it progresses from the exterior to the interior environments. The remaining two curves represent the vapour pressure (VP) and the saturated vapour pressure (SVP) throughout the assembly. If the VP exceeds the SVP, it indicates condensation will occur at the point where the two curves intersect. This location is denoted by an arrow, and corresponds to the dewpoint in the assembly.

Case no. 1: Condensation occurs

There is condensation in the given assembly at this location.
The condensation rate is 1.587E-06 g/m²/sec.
or 1.320E-04 litres/m²/day.
The estimated cost for the materials in this assembly is 150.8 \$/m².
The heat loss rate is 14.08 Watt/m².
The dewpoint temperature is -17.8 degrees Celsius.

Case no. 2: No condensation occurs

There is no condensation for these conditions.
The estimated cost for the materials in this assembly is 1638 \$/m².
The heat loss rate is 83.12 Watt/m².

The result of the analysis is displayed in terms of condensation rate and heat loss. If condensation occurred, there will be an arrow indicating the exact location. The condensation rate due to diffusion, estimated cost of materials in the assembly, heat loss rate and the dewpoint are all calculated and displayed as seen on the left. **Note that the effect of air leakage is not considered in these results.**

Figure 1 Example of Computer Modeling Output

dynamic buffer zone system was analyzed as a static assembly due to the limitations of the modeling software.

The report cautions that, as a result of disregarding the effects of air leakage, the results for the rate of condensation due to diffusion produced from the simulations are very low (no higher than 5.5 ml/sq-meter/day in any of the assemblies simulated). Given the ability of a brick masonry wall to absorb at least 1 per cent of its mass as vapour, a 200-mm thick double wythe wall could potentially store as much as 3,600 ml (1% x 1,800 kg/ m³ x 0.2 m) in water vapour. The effect on the moisture content within the masonry wall of these assemblies due to diffusion alone is insignificant.

BUILDING EVALUATIONS

Table 2 of the report provides a summary of all the buildings reviewed and general observations recorded during the physical assessment of each of the 10 buildings selected and reviewed in early 2003.

The first three columns of Table 2 of the report include respectively,

Table 1 Summarized Results of Computer Modeling of Masonry Walls

Case Study	Original Construction					Retrofit Construction				
	RSI	R	Rate of Condensation (ml/sq-m/day)	Heat Loss Rate (Watts/sq-m)	Dewpoint Temperature (°Celsius)	RSI	R	Rate of Condensation (ml/sq-m/day)	Heat Loss Rate (Watts/sq-m)	Dewpoint Temperature (°Celsius)
1	0.25	1.4	None @ 20.0% RH	174.66	N/A	3.12	17.7	0.04 @ 20% RH	14.09	-19.9
2	0.62	3.5	10 @ 35% RH	71.17	1.9	2.15	12.2	0.13 @ 35% RH	20.5	-18.2
3	0.53	3	None at 35% RH	83.12	N/A	N/A	N/A	N/A	N/A	N/A
4	0.39	2.2	None at 35% RH	112.96	N/A	1.95	11.1	1.7 @ 35% RH	22.52	-2.9
5	0.25	1.4	None @ 25.0% RH	177.79	N/A	2.55	14.5	2.6 @ 25% RH	17.26	-10.3
6	0.31	1.8	0.71 at 35% RH	141.99	4.6	1.93	11	5.5 @ 35% RH	22.77	-0.4
7	0.37	2.1	0.14 at 35% RH	120.06	1.7	2.31	13.1	4.5 @ 35% RH	19.02	-1.3
8	0.58	3.3	3.0 at 35% RH	75.51	1	2.91	18.5	0.006 @ 35% RH	15.12	-18.2
9	0.31	1.8	0.7 at 35% RH	141.99	4.6	2.61	14.8	3.8 @ 35% RH	16.87	-3.3
10	0.39	2.2	None at 35% RH	112.96	N/A	1.94	11	0.14 @ 35% RH	22.67	-13.9

Notes: 1. The rate of condensation (diffusion) indicated in the table above is based upon computer simulations under steady state conditions.

2. The exterior ambient temperature for all simulations was fixed at -23 °C, with an exterior ambient humidity of 90 per cent RH, while the interior ambient temperature was fixed at 21 °C.

Due to limitations with the modeling software, the effect of thermal mass, solar heating, and air leakage on the rate of condensation was not considered in the results generated by the computer simulation.

Table 2 Summarized Results of Performance Assessment of Masonry Walls

Exterior Wall Retrofit Composition							Results	
Case Study	Year Built	Year of Retrofit	Original Cladding	New Insulation	New Interior Finish	General	Visual Observations	Modeling Results (Comparative)
1	1884	1984	Brick (double wythe)	¼ in. - 1 in. polyurethane foam and 1½ in. glass fibre batts	½ in. gypsum board with aluminum foil backing	- 4-storey, rectangular - 50% glazing - no overhang - precast concrete sills	No visible changes observed in the condition of the masonry between visits conducted in 2000 and 2003	Increased rate of condensation in the wall assembly
2	1927	2002	4 in. clay brick with 8 in. terra cotta block backing	1 in. plaster and 1 in. polyurethane foam	Polyethylene VB, steel furring, ½ in. gypsum board	- 11-storey, rectangular - 60% glazing - no overhang - precast concrete sills - exposed on two sides	Some minor efflorescence at windowsill and dark staining of bricks (2 facades)	Reduced rate of condensation in the wall assembly
3	1910	2003	28 in. - 38 in. of solid stone	None	None	- 4-storey, rectangular - 10% glazing - projecting cornice - exposed on 4 sides	No masonry deficiencies observed	Not applicable
4	1918	2002	18 in. solid stone	2 in. glass fiber	½ in. gypsum board with steel stud framing	single family home 15% glazing sloped roof with gutters roof overhangs	Recently re-pointed no apparent deficiencies	Inconclusive: DBZ system with 1 in. controlled and heated air space
5	1861	2003	Stone/Brick	1½ in. polyurethane foam	Steel stud wall assembly with ½ in. gypsum board	- 6-storey, rectangular - 40% glazing cornices	Cracks observed where stone facade meets with brick facade at corner	Increased rate of condensation in the wall assembly
6	1854 -1946	2003	Variable masonry compositions (12)	1 in. polyurethane foam	Steel stud wall assembly with ½ in. gypsum board	- 8-storey, rectangular - 20% glazing - no overhang/cornice - exposed on 4 sides	Retrofit work ongoing	Increased rate of condensation in the wall assembly
7	1920	2001	4 in. Fieldstone, and 3 wythes of clay brick	1¼ in. polyurethane foam	Steel stud wall assembly, glass fibre insulation, aluminum foil backed ½ in. gypsum board	single family home 15% glazing sloped roof w. overhangs no gutter	Good condition, One minor crack observed	Increased rate of condensation in the wall assembly
8	1906	1996	4 in. brick, 2 in. air space, and 8 in. concrete block	1½ in. polyurethane foam	Steel furring, Type I VB, ½ in. gypsum board	- 6-storey, rectangular - 40% glazing - no overhang/cornice	No apparent deficiencies	Reduced rate of condensation in the wall assembly
9	1930	1999	13 in. of brick (triple wythe)	1½ in. polyurethane foam	Steel stud wall assembly with ½ in. gypsum board	- 6-storey, rectangular - 40% glazing	Cracks observed in brickwork at one corner of building	Increased rate of condensation in the wall assembly
10	1890-1905	2001	18 in. - 24 in. Limestone blocks	1 in. polyurethane foam	Liquid VB, 2 in. wood stud wall, ½ in. gypsum board	single family home 25% glazing sloped roof with gutters roof overhangs	No apparent deficiencies	Increased rate of condensation in the wall assembly

SUMMARY AND DISCUSSION

In comparing the results of the computer modeling of both the original and the retrofit wall assemblies, the report suggests that increasing the thermal resistance along the inside face of the existing masonry wall in six of eight measurable cases produced conditions favorable to increasing the rate of condensation in the wall assembly under identical ambient conditions (temperature and relative humidity). Consequently, the report concludes that there is, theoretically, an increased possibility of masonry deterioration related to these particular case studies. However, the report notes that, in all cases, very little or no visible signs or evidence of deterioration were noted at the time of the survey with the exterior solid masonry walls of the buildings which could be directly attributable to the retrofit approach used.

The apparent discrepancy between the results of the computer modelling which showed a comparative increase in the rate of condensation in six of the cases and the visual exterior review of the masonry walls which revealed no evidence of deterioration, could be explained by the following

- The preliminary results at this time appear to suggest that, over the short term, insulating solid masonry walls does not appear to result in the deterioration of the exterior solid masonry wall when the retrofit approach involves the installation of a suitable air and vapour barrier.
- While conditions for freeze-thaw action may be present, this may not be sufficient to damage the masonry assembly.
- An air-space behind the exterior masonry on the cold side of the new air barrier appears to benefit the retrofit approach. In the two cases where an air space was provided on the cold side of the air barrier, static modeling showed a reduction in the comparative rate of diffusion condensation in the retrofit wall assembly. An added benefit of this cavity or air space, as in the case of common single wythe brick veneer cavity wall buildings, is that it provides improved drainage in pressure equalized wall designs, reduces moisture entrapment in the wall itself, and improves the drying rate of the exterior masonry wythes through convection and air travel along the back face of the masonry.

It is anticipated that the results of the preliminary performance evaluations gathered in this research project will act as benchmarks when future evaluations of these same exterior solid masonry walls will be conducted.

CMHC Project Manager: Bill Semple

Research Consultants: Mario Goncalves, Patenaude-Trempe Inc.

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Canada Mortgage and Housing Corporation
700 Montreal Road
Ottawa, Ontario
K1A 0P7

Phone: 1-800-668-2642
Fax: 1-800-245-9274

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